PALEONTOLOGY AND PALEOECOLOGY OF EARLY MIOCENE SEQUENCES IN HAYS AND TIPAKURI STREAMS, NORTHERN HUNUA RANGES, AUCKLAND

MICHAEL EAGLE AND BRUCE W. HAYWARD

AUCKLAND INSTITUTE AND MUSEUM

Abstract. One hundred and thirty-one macrofossil taxa (51 gastropods, 35 bivalves, 19 corals, 9 fish (otoliths), 4 scaphopods, 4 brachiopods, 4 barnacles, 3 polychaetes, 1 shark (tooth), 1 echinoderm) are recorded from two rich, early Miocene (Otaian), Waitemata Group fossil beds exposed in Hays and Tipakuri Streams in the northern Hunua Ranges. Ninety-seven species of foraminifera (protozoan microfossils) are recorded from six faunas recovered from the associated strata. These macro- and microfossil faunas are used to interpret the paleoenvironmental history of the area.

The previously unrecorded Tipakuri Stream fauna in basal Waitemata Group muddy sandstone (Kawau Subgroup) appears to be an in-situ assemblage that accumulated at mid to outer shelf depths during the early subsidence of the Waitemata Basin.

The Hays Stream macrofauna, from which 35 taxa had previously been recorded, occurs in Waitemata Group strata transitional between the basal shallow water Kawau Subgroup and the deep bathyal Warkworth Subgroup flysch that filled most of the Waitemata Basin. The Hays Stream macrofauna contains a mixed assemblage that we interpret to be derived from four distinct groups of communities: i. intertidal and shallow subtidal sand and mud communities; ii. intertidal and shallow subtidal rock and coarse gravel communities; iii. inner to mid shelf silt, sand and fine gravel communities; iv. outer shelf to upper bathyal mud and sand community. Shells, gravel, sand and mud from these communities are inferred to have mixed together in a mass flow that carried them down to deep upper bathyal depths (500-1000 m), during the period of major subsidence of several thousand metres that formed the Waitemata Basin.

The geology of the northern Hunua Ranges in the vicinity of Hays and Tipakuri Streams has been mapped by Laws (1931), Healy (1935) and Kear (1959). All three produced columns to illustrate the basic stratigraphy observed in Hays Stream, as have Waterhouse (1974) and Hayward and Brook (1984).

Clarke (1905) published the first list of macrofauna collected from Hays Stream (then called Slippery Stream). He recorded 18 species of molluscs, 4 brachiopods, 1 echinoderm and 2 corals. From this locality he described two new species, *Flabellum papakurense* and *Amussium papakurense*. Marwick (in Laws 1931) added a further 7 mollusc species records from Hays Stream. Squires (1958) added records of three further corals from this locality.

GEOLOGY (Fig. 1)

The northern Hunua Ranges are primarily composed of Permian to Jurassic greywacke (Waiheke Group, Schofield 1976) capped in places by the eroded remnants of two thin middle Cenozoic transgressive sequences. The older of these is a late Eocene to early Oligocene sequence. Only remnant patches of the lower parts of this Te Kuiti Group sequence (Waikato Coal Measures and Mangakotuku Siltstone) are preserved in this area. The younger transgressive sequence is of the early Miocene Waitemata Group. It progressively buried an irregular coastal topography of actively eroding greywacke and lower Te Kuiti Group rocks.

The basal Waitemata Group rocks (Kawau Subgroup, Hayward and Brook 1984) consist of c. 10 m of shallow-water sandy conglomerate and sandy limestone (Papakura Limestone), that pass laterally into c. 8 m of fossiliferous, partly glauconitic, calcareous sandstone (Tipakuri Sandstone). The best exposed sequence of basal conglomerate and limestone occurs on the northern bank of Hays Stream (Fig. 1) and the best exposed sequence of fossiliferous sandstone occurs in Tipakuri Stream.

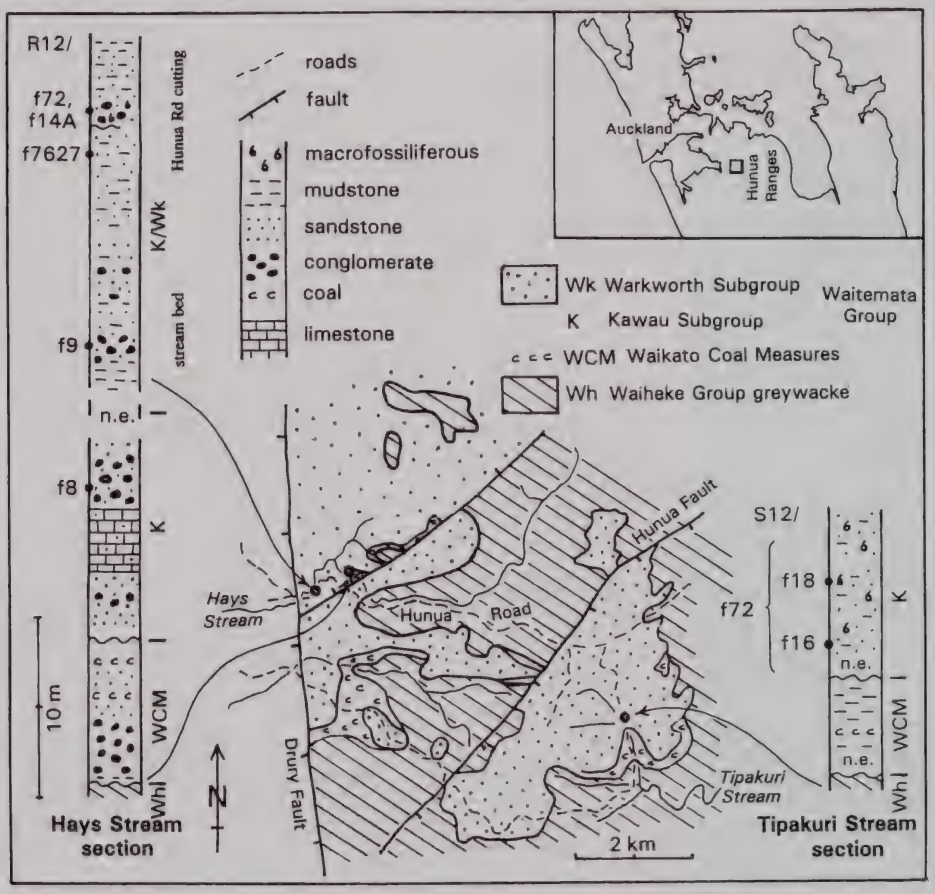

Fig. 1. Geological map of the northwestern Hunua Ranges (after Kear 1959 and Schofield 1976) showing the location of early Miocene stratigraphic columns for Hays and Tipakuri Streams; n.e. = not exposed.

As with other thin, basal Waitemata sequences, these shallow-water sediments pass rapidly up into deeper water deposits. This transition records a period of substantial subsidence early in the history of the Waitemata Basin (Ricketts et al. 1989). In some places, deep bathyal flysch, transported into the basin from the north-west, directly overlies the shallow-water sequence and indicates a period with little or no sediment supply during subsidence. Elsewhere (e.g. Motutapu, Motuihe), 1-20 m of locally-derived sediment (greywacke lithoclasts and bioclasts) accumulated in upper bathyal depths and document the episode of rapid subsidence (Ricketts et al. 1989) adjacent to an eroding coastline that had not yet been drowned. In most parts of the northern Hunua Ranges there is an abrupt transition from basal shallow-water Waitemata sediments to deep bathyal flysch (Hayward and Brook 1984, fig. 3), except at Hays Stream. Here, at the downstream end of the Hays Stream gorge are 30 m of locally-derived sandstone, siltstone and shelly conglomerate (greywacke and Te Kuiti Group lithoclasts) exposed in the stream-bed and bluffs above and below Hunua Road. There are no exposed lower or upper contacts for this unit, but the stratigraphic sequence elsewhere indicates that it overlies the basal, shallow-water Kawau Subgroup exposed 500 m upstream, and underlies the deep bathyal flysch sequence that outcrops in the hills within 1 km to the north.

This paper documents the early Miocene macrofauna and foraminiferal microfaunas of the Kawau Subgroup at Tipakuri Stream, the microfauna of the Kawau Subgroup at Hays Stream, and the macrofauna and microfaunas of the locally-derived transitional Waitemata Group sequence at Hays Stream (Fig. 1).

Fossil record numbers are those of the New Zealand Fossil Record File. All macrofossils are held in the collections of Auckland Museum and all microfossils are held by the Institute of Geological and Nuclear Sciences, Lower Hutt.

MACROFAUNA

All collected taxa are listed in Appendix 1. The paleoecological and paleoenvironmental assessment that follows is largely based on the known ecology of genera living today and of modern species most closely related to these fossils.

HAYS STREAM FAUNA (R12/f72)

The rich macrofauna from the transitional Waitemata Group sequence collected from a cutting on the Papakura-Hunua Road above Hays Stream has variable preservation, with some specimens in near perfect condition and others partly decalcified or broken into many pieces, probably during pre-burial transport.

The Hays Stream fauna occurs in a bed of muddy, shelly conglomerate and appears to have been mixed during pre-burial downslope transport in a subaqueous mass flow. Faunal elements from at least four different communities, or groups of communities, are identifiable within this single Hays Stream fossil fauna and are discussed separately below.

Intertidal and Shallow Subtidal Mud and Sand Communities, 0-10 m (Fig. 2)

A significant number of fossils in the Hays Stream fauna are inferred to have lived in or on soft sediment intertidally or to depths no greater than 10 m. Many of these fossils were

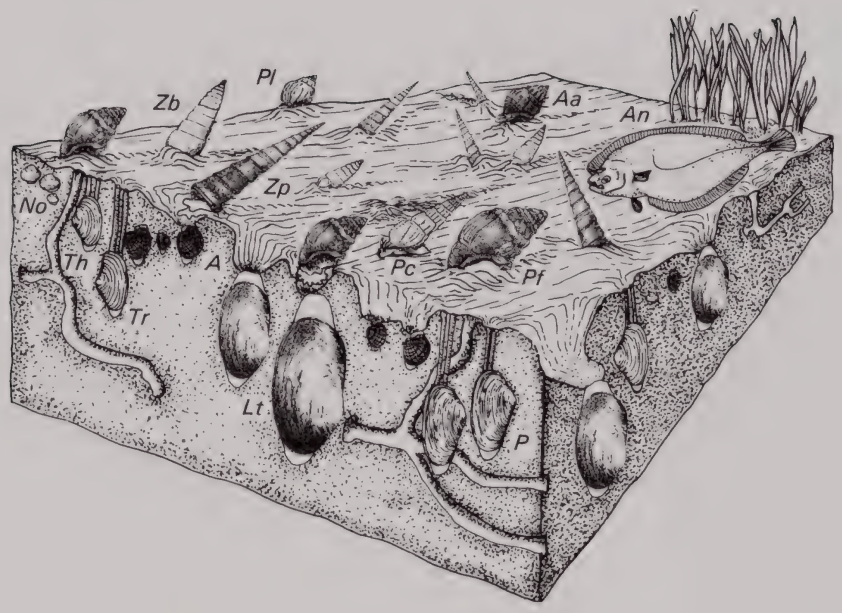

Fig. 2. Schematic drawing of Hays Stream intertidal and shallow subtidal mud and sand communities (0-10 m). A = *Austrovenus* n.sp.; Aa = *Austrofusus (Neocola) alpha*; An = *Arnoglossus novus*; Lt = *Lutraria trapezoidalis*; No = *Nucula otamatea*; P = *Paphies* n.sp.; Pc = *Pyrazus consobrinus*; Pf = *Paracominia finlayi*; Pl = *Paracominia lignaria*; Th = *"Tellina" hesterna*; Tr = *"Tellina" robini*; Zb = *Zeafallacia benesulcata*; Zp = *Zeacolpus pukeuriensis*.

infaunal deposit-feeding bivalves, such as two species of the long siphonate genus *"Tellina"*, the elongate mactrid *Lutraria trapezoidalis*, undescribed species of the cockle *Austrovenus* and tuatua *Paphies*, and the small nut shell *Nucula otamatea*.

The shallow water gastropods may be divided into those that lived in exposed and those that lived in sheltered conditions. From exposed environments there is the extinct *Austrofusus (Neocola),* which presumably lived alongside *Zethalia* at or below low tide on a moderately exposed sandy beach. *Zeacolpus* probably lived in current-swept shallow subtidal situations. Elements from a sheltered, slightly brackish estuarine environment include the carnivorous gastropods *Zefallacia*, *Paracominia* and *Pyrazus*. The latter genus is currently a "mangrove creeper" in tropical areas (Beu et al. 1990). The high-spired, infaunal gastropod *Zeacuminia* probably resided in upper intertidal brackish situations, as it does today. Otoliths tell of the presence of the left-eyed flounder *Arnoglossus* which presumably also lived around this environment.

Intertidal and Shallow Subtidal Rock and Coarse Gravel Communities, 0-30 m (Fig. 3)

Intertidal and shallow subtidal rocky reef dwellers in the Hays Stream fauna include the rock boring bivalve *Parapholas aucklandica*, the sedentary byssate *Pteria oneroaensis* and an unidentified oyster. Rocky reef inhabiting gastropods include the intertidal carnivores *Lepsiella* and *Pagodula waitemataensis*, and the very large *Sarmaturbo superbus*.

Pieces of the hermatypic corals *Cyphastrea* and *Leptastrea* are inferred to have originated from scattered heads growing on a coarse gravelly substrate in shallow water. Other members of this "subtidal gravel bank" community probably included the ahermatypic corals *Dendrophyllia*, *Oculina* and *Flabellum*, and the brachiopods *Magasella*, *Notosaria* and *Terebratulina*. The large, thick-shelled bivalves *Glycymerita*, *Eucrassatella* and *Tucetona* probably also lived in this shallow gravel community as did the epifaunal carnivorous gastropods *Conus* and *Conilithes* and the large cidarid *Phyllacanthus titan*, which is represented in the fossil fauna by its large spines. The ciliary-feeding *Crepidula* probably lived in clusters attached to pebbles or large shells and *Chama* lived cemented by one valve to any available hard substrate.

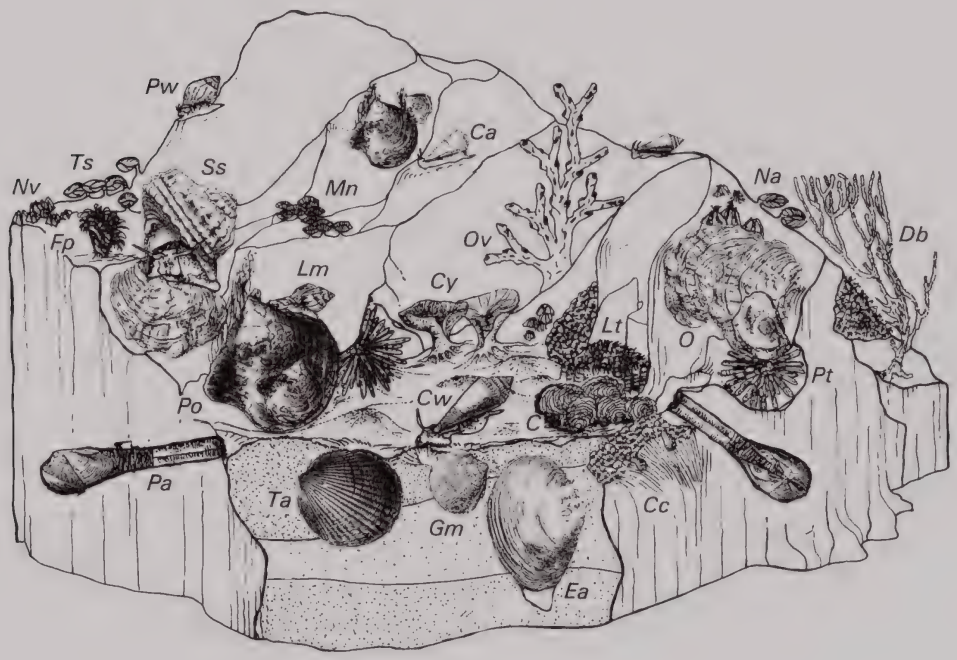

Fig. 3. Schematic drawing of Hays Stream intertidal and shallow subtidal rock and coarse gravel communities (0-30 m). C = *Chama* n.sp.; Ca = *Conus* (s.l.) *armoricus*; Cc = *Cyphastrea* cf. *chalcidium*; Cw = *Conolithes wollastoni*; Cy = *Cyathoceras* sp.; Db = *Dendrophyllia boschmai*; Ea = *Eucrassatella ampla*; Fp = *Flabellum pavoninum*; Gm = *Glycymerita (Manaia)* cf. *manaiaensis*; Lm = *Lepsiella maxima*; Lt = *Leptastrea* cf. *transversa*; Mn = *Magasella neozelandica*; Na = *Notosaria antipoda*; Nv = *Notobalanus vestitus*; O = *Ostrea* sp.; Ov = *Oculina* cf. *virgosa*; Pa = *Parapholas aucklandica*; Po = *Pteria oneroaensis*; Pt = *Phyllacanthus titan*; Pw = *Pagodula waitemataensis*; Ss = *Sarmaturbo superbus*; Ta = *Tucetona aucklandica*; Ts = *Terebratulina suessi*.

Inner to Mid Shelf Silt, Sand and Fine Gravel Communities, 10-100 m (Fig. 4)

Gastropods that are inferred to have lived in this community are abundant and diverse in the Hays Stream fauna. Apart from the deposit-feeding turritellids *Maoricolpus*, *Tropicolpus* and *Zeacolpus*, the majority were carnivorous predators e.g. *Alcithoe*, *Polinices*, *Cabestana, Pterynotus, Eumitra, Amalda, Austrotoma* and *Gemmula.*

The deep-burrowing, long-siphoned, suspension feeders *Dosinia*, *Kuia* and *Panopea* seem to have been the dominant bivalves. Also present are the shallower burrowing suspension feeders *Notocorbula* and *Caryocorbula* and the byssate bivalve *Chlamys*. *Isognomon* possibly lived epifaunally as a cluster of individuals byssally attached to each other, whereas *Lentipecten* lived on a sandy substrate and was able to swim off if disturbed. The infaunal scaphopods *Antalis, Fissidentalium* and *Dentalium* were probably all present in the silt and fine sand of this habitat.

Several different free-living or attached forms of bryozoa and the ahermatypic corals *Flabellum, Truncatoflabellum, Caryophyllia japonica* and *Oculina* may also have lived in this community. Otoliths suggest the presence in this habitat of the burrowing bandfish *Cepola* and the demersal cardinal fish *Coelorhynchus*. The sand shark *Odontaspis* is represented by several fossil teeth.

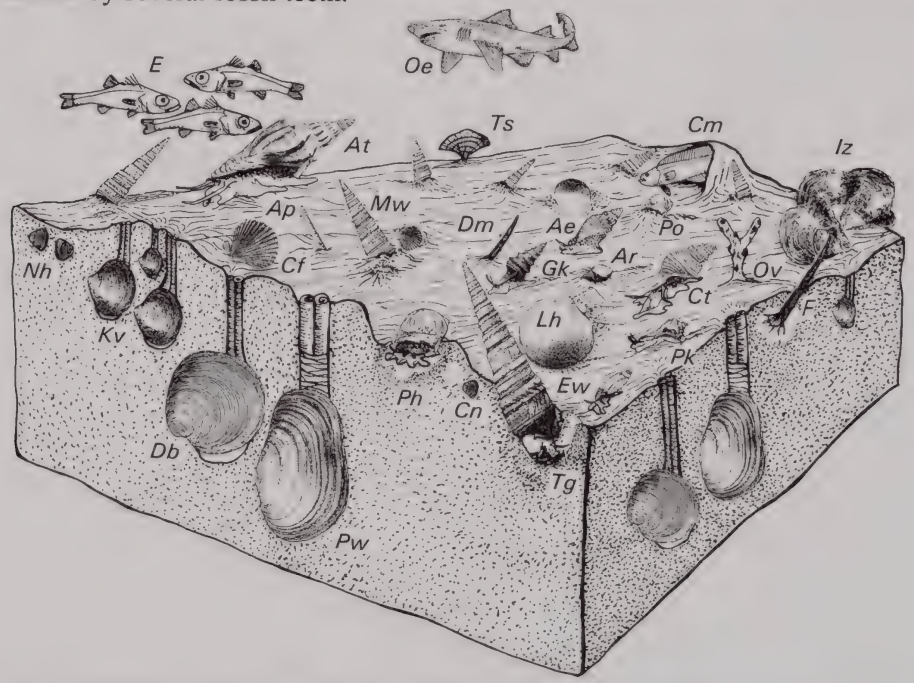

Fig. 4. Schematic drawing of the Hays Stream inner to mid shelf silt, sand and fine gravel communities (10-100 m). Ae = *Austrotoma excavata*; Ap = *Antalis pareorensis*; Ar = *Amalda (Baryspira) robusta*; At = *Alcithoe (Alcithoe) turrita*; Cf = *Chlamys fischeri*; Cm = *Cepola* cf. *macrophthalma*; Cn = *Caryocorbula nitens*; Ct = *Cabastana tetleyi*; Db = *Dosina (Raina) bensoni*; Dm = *Dentalium mantelli*; E = *Epigonus* sp.; Ew = *Eumitra waitemataensis*; F = *Fissidentalium* n.sp.; Gk = *Gemmula kaiparaensis*; Iz = *Isognomon* aff. *zealandicus*; Kv = *Kuia vellicata*; Lh = *Lentipecten hochstetteri*; Mw = *Maoricolpus waitemataensis*; Nh = *Notocorbula humerosa*; Oe = *Odontapsis elegans*; Ov = *Oculina virgosa*; Ph = *Polinices huttoni*; Pk = *Pterynotus* cf. *kaiparaensis*; Po = *Polinices oneroaensis*; Pw = *Panopea worthingtoni*; Tg = *Tropicolpus (Amplicolpus) gittosinus*; Ts = *Truncatoflabellum sphenodeum.*

Outer Shelf to Upper Bathyal Soft Bottom Community, 100-500 m (Fig. 5)

Elements in the Hays Stream fauna that appear to be derived from a quiet, moderately deep water, soft bottom habitat include abundant shells of the deposit-feeding bivalve *Limopsis*, and less common *Pseudoportlandica*, *Neilo*, *Bartrumia*, *Lima* and *Mesopeplum*. Carnivorous gastropods that probably lived at these depths include *Nassarius*, *Chicoreus*, *Teremelon*, *Bathytoma* and the opisthobranchs *Acteon*, *Cylichnania* and *Cylichnina*.

Ahermatypic corals that were attached to pebbles or shells or nestled in these soft sediments at outer shelf or upper bathyal depths probably include *Notocyathus pedicellatus*, *N. conicus*, *Trochocyathus papakurensis*, *Stephanotrochus* and the gorgonian *Parisis hamiltoni*. The barnacles *Smilium*, *Notobalanus*, *Tasmanobalanus* and *Graviscalpellum* all probably lived at these depths (Buckeridge 1983) attached to shells or pebbles that lay on the sea floor.

Fish otoliths that probably originated at these depths include those of the cosmopolitan *Melanonidarum*, an uncommon pelagic cod, and the alfonsino *Centroberyx*. Another is the ghost flathead *Hoplichthys*, which is a deep water benthic fish.

TIPAKURI STREAM FAUNA (S12/f72) (Fig. 6)

The macrofauna from Tipakuri Sandstone (Kawau Subgroup) in the bank of Tipakuri Stream comes from a 5 m thick bed of slightly glauconitic, calcareous sandstone. The fossils are badly decalcified and many are distorted by post-burial deformation.

The Tipakuri fauna appears to lack the mixing that characterises the Hays Stream fauna, and is essentially an in-situ fauna from mid to outer shelf depths (50-200 m). It is dominated by the infaunal suspension feeding bivalves *Bartrumia oneroaensis*, *Spissatella trailli* and *Panopea worthingtoni*, the epifaunal bivalve *Limopsis*, and the carnivorous naticid gastropod *Polinices*. Other members of this muddy sand community include *Lima colorata*, *Fissidentalium* and rare *Struthiolaria lawsi*.

RECORDS OF NEW OR RARE TAXA

The Hays Stream fossil fauna contains several mostly shallow water molluscs that have only been found in one or two other localities, largely because of the rarity of intertidal and shallow subtidal fossil assemblages in the early Miocene of New Zealand. These include: *Pteria oneroaensis*, *Lutraria trapezoidalis*, *Dosinia (Raina) bensoni*, *Sarmaturbo superbus*, *Zefallacia benesulcata*, *Pyrazus consobrinus*, *Tropicolpus (Amplicolpus) gittosinus*, *Cabestana tetleyi*, *Parapholas aucklandica*, *Lepsiella intermedia* and *L. maxima*. A possible new genus of the gastropod family Cerithiidae and a coelenterate of the family Caryophylliidae, are also recorded. Also present are apparently new species of the bivalves *Neilo*, *Mesopeplum*, *Chama*, *Paphies* and *Austrovenus*, the gastropods *Zethalia*, *Proerato* and *Lepsiella* and the scaphopod *Fissidentalium*. A new record for the Waitemata Basin is the rare serpulid, *Sclerostyla ouyenensis*, previously recorded by Finlay (1924) from Miocene strata at Pukeuri and Clifden. Uncommon species found in the Tipakuri Stream fauna are *Struthiolaria lawsi* and *Bartrumia oneroaensis*.

Fig. 5. Schematic drawing of the Hays Stream outer shelf to upper bathyal soft bottom community (100-500 m). Ao = *Acteon oneroaensis*; Bb = *Bathytoma (Bathytoma) bartrumi*; Ca = *Coelorhynchus australis*; Ck = *Chicoreus (Siratus) komiticus*; Cp = *Centroberyx* cf. *Trachichthodes pulcher*; Fp = *Flabellum pavoninum*; Hm = *Hoplichthys multistriatus*; Lc = *Limopsis catenata*; Lcl = *Lima colorata*; Lz = *Limopsis zelandica*; M = *Mesopeplum* n.sp.; Ma = *Melanonidarum* aff. *Karrerichthys admirabilis*; N = *Neilo* n.sp.; Np = *Notocyathus (Paradeltocyathus) pedicellatus*; Ns = *Nassarius (Hima) separabilis*; Ph = *Parisis hamiltoni*; Tg = *Tasmanobalanus grantmackiei*; Tp = *Trochocyathus (Aplocyathus)papakurensis*; Tt= *Teremelon tumidor*.

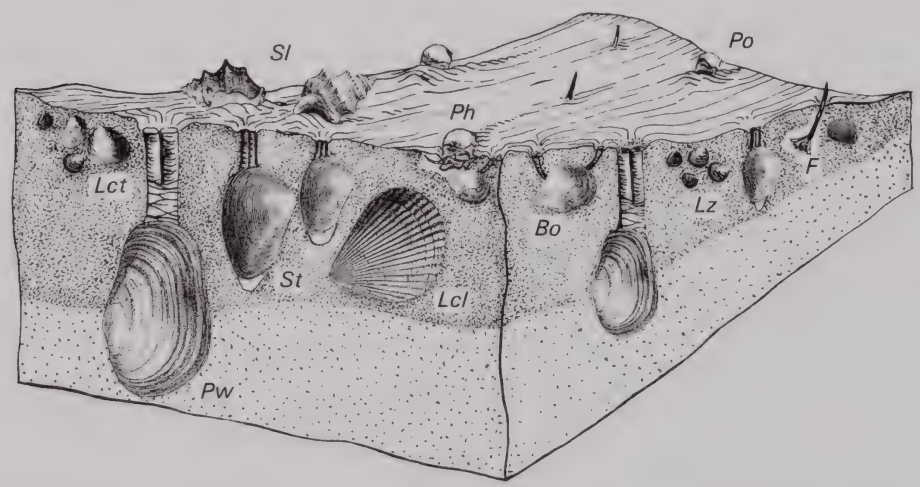

Fig. 6. Schematic drawing of the Tipakuri Stream in-situ sandy soft bottom community (50-200 m). Bo = *Bartrumia oneroaensis*; F = *Fissidentalium* n.sp.; Lct = *Limopsis catenata*; Lcl = *Lima colorata*; Lz = *Limopsis zelandica*; Ph = *Polinices huttoni*; Po = *Polinicesoneroaensis*; Pw = *Panopea worthingtoni*; Sl = *Struthiolaria lawsi*; St = *Spissatella trailli*.

MICROFAUNA

Six sediment samples (4 from Hays Stream, 2 from Tipakuri Stream - Fig. 1) were processed for microfaunal assessment and a quantitative pick of 100 benthic foraminifera was made from five of these. An assessment of the percentage of planktic foraminifera in each sample was also made. All taxa have been identified and their counts tabulated in Appendix 2. Paleoenvironmental assessments are largely based on Hayward (1986).

PLANKTIC FORAMINIFERA

The Hays Stream faunas contain varied percentages of planktics. The lowest sample (R12/f8) contains a low 10% planktics suggesting neritic waters overhead and probably inner or mid shelf depths (0-100 m). The two middle, sandstone samples (R12/f9, f7627) contain 95% and 75% planktics indicating oceanic to marginal oceanic water overhead and paleodepths in the upper to mid bathyal range (200-2000 m). The highest sample, the matrix of the richly fossiliferous sandy conglomerate (R12/f14A), contains 40% planktics which indicates marginal neritic overhead water and suggests an outer shelf to uppermost bathyal depth range. The planktic fauna in these last three samples is diverse and contains numerous large specimens, which is also indicative of oceanic, bathyal conditions.

The two Tipakuri Stream faunas contain 25% and 45% planktics indicating marginal neritic waters usually associated with a mid shelf to uppermost bathyal depth range (50-400 m).

BENTHIC FORAMINIFERA

Hays Stream - R12/f8

The lowest Hays Stream fauna is dominated by *Gaudryina convexa, Cribrorotalia ornatissimum, Melonis simplex, Cibicides mediocris, C. notocenicus* and *Elphidium gibsoni*. This assemblage is characteristic of those living in a high energy, coarse sediment, shallow water environment (inner shelf, 10-50 m). There are no genera present that are today restricted to deeper water. Indeed many of the rarer taxa are also characteristic of shallow water (e.g. *Amphistegina, Discorbis, Eponides repandus, Haynesina depressula, Notorotalia powelli, Pileolina, Planoglabratella* and *Textularia hayi*).

Hays Stream - R12/f9

This benthic fauna is sparse and consists of a mixture of several characteristically inner shelf taxa (*Cribrorotalia, Cibicides notocenicus*) and a number of quiet water taxa typical of outer shelf or upper bathyal depths (*Alabamina, Gyroidina, Oridorsalis, Stilostomella pomuligera*).

Hays Stream - R12/f7627

The fauna is dominated by *Cibicides mediocris, C. temperatus, C. vortex, Bolivina reticulata* and *Trifarina parva*. This assemblage is similar to thanatotope B of Hayward and Buzas (1979) which is characteristic of outer shelf depths (c. 100-200 m). Also present in f7627 are several typical bathyal or bathyally-restricted taxa (e.g. *Stilostomella pomuligera,*

Oridorsalis, Osangularia, Planulina). The shallowest known modern record of *Osangularia* is 700 m (Hayward and Buzas 1979: 21) and a similar upper depth limit has been determined from its occurrence in the Miocene of Taranaki (Hayward 1990, table 1). This fauna therefore indicates that most of the sand was derived from outer shelf depths and was transported downslope, picking up minor amounts of bathyal sediment en route, before coming to rest in the deep upper bathyal (c.500-1000 m).

Hays Stream - R12/f14A

The benthic fauna in the matrix of this richly macrofossiliferous conglomerate appears to be a mixture of two assemblages. It is dominated by robust *Amphistegina aucklandica*, a species diagnostic of a high energy, inner shelf environment. Other shallow subtidal taxa present include *Arenodosaria antipoda, Cibicides notocenicus*, *Dorothia minima* and the larger foraminifer *Lepidocyclina orakiensis*. Subdominant are *Cibicides mediocris, C. vortex, C. temperatus* and *Globocassidulina subglobosa* - an assemblage typical of finer sediment at outer shelf depths.

Tipakuri Stream

Both faunas (S12/f16, f18) are dominated by a combination of *Nonionella novozealandica*, *Cassidulina laevigata, Cibicides mediocris, C. temperatus, C. vortex, Bolivina mantaensis* and *B. semitruncata*. This assemblage is characteristic of sheltered muddy sand at mid to outer shelf depths (50-150 m). The lower sample (f16) has *Cribrorotalia ornatissima* and *Virgulopsis pustulata* as additional codominants suggesting a slightly less sheltered and shallower environment than the higher (f18). These two faunas are very similar in composition to assemblages in muddy sandstones in the basal Waitemata sequence on Waiheke Island (pers. obs.).

AGE

The presence of the molluscs *Alcithoe turrita* (Po-Pl), *Lutraria trapezoidalis* (Po-Pl), *Tropicolpus gittosinus* (Lw-Po), *Austrotoma finlayi* (Lw-Po) and *Parapholas aucklandica* (Po) in the Hays Stream fauna (R12/f72) gives an early Miocene (Otaian, Po) age. An Otaian age is also inferred for the Tipakuri Stream fauna based on the presence of *Bartrumia oneroaensis* which is known only from Otaian strata at Oneroa, Waiheke Island and in the Mount Harris Formation (Beu et al. 1990).

The presence of the foraminifera *Catapsydrax dissimilis* (Lwh- Po), *Haeuslerella hectori* (Lw-Po) and *Ehrenbergina marwicki* (Po-Pl) in the Hays Stream microfaunas (R12/f7627) confirms an Otaian age. The Tipakuri Stream foraminiferal faunas do not provide such a precise age diagnosis, although they are consistent with a similar age to the Hays Stream faunas.

PALEOCLIMATE

MACROFAUNA

The macrofossil faunas of Hays and Tipakuri Streams are rich in genera that live today in warm, subtropical waters at or beyond the northern extreme of the New Zealand region.

These include the molluscs *Pteria, Isognomon, Chama, Eucrassatella, Lutraria, Parapholas, Pyrazus, Proerato, Polinices* (s.s.), *Chicoreus (Siratus), Conus* (s.l.), *Conilithes, Gemmula*, and *Bathytoma* (s.s.) and the cidarid echinoderm *Phyllacanthus* (Beu et al. 1990, Fell 1954). In addition there are extinct genera, some apparently endemic to New Zealand, that by their affinities also appear to indicate subtropical conditions in New Zealand in the Otaian. These include *Lentipecten, Spissatella, Bartrumia, Kuia, Dosinia (Raina), Sarmaturbo, Zefallacia, Pareora, Austrofusus (Neocola), Zeacuminia, Austrotoma*, and *Maudrillia* (Beu et al. 1990).

Pieces of two genera of reef coral nave been found in the Hays Stream fauna. No reef corals currently live around mainland New Zealand. Comparison of the full early Miocene reef coral fauna of northern New Zealand with the modern ranges of the genera indicates that sea surface temperatures were 5-7°C warmer than present (Hayward 1977).

MICROFAUNA

The foraminiferal faunas of Hays and Tipakuri Streams include locally abundant *Amphistegina aucklandica* and occasional specimens of the larger foraminifera *Lepidocyclina orakiensis*. Neither larger foraminifera nor *Amphistegina* live around New Zealand today, but both are abundant in shallow environments in the tropical South Pacific from Norfolk Island northwards. These occurrences support inferences from other fossil groups that the early Miocene climate of northern New Zealand was marginally tropical (Hornibrook 1971).

DISCUSSION

TIPAKURI STREAM PALEOENVIRONMENT

Both macro- and microfaunas (S12/f16, f18, f72) appear to be in-situ, unmixed assemblages that indicate a mid shelf environment deepening to outer shelf depths during the period of accumulation.

HAYS STREAM PALEOENVIRONMENT

The microfossil faunas from the Miocene sequence in Hays Stream support previous interpretations of a transgressive sequence. The basal conglomerate and limestone (Kawau Subgroup, R12/f8) accumulated at inner shelf depths in a high energy environment. The area had subsided to deep upper bathyal (500-1000 m) by the time the transitional Waitemata Group sequence was accumulating. The micro- and macrofaunas (R12/f9, f14A, f7627, f72) indicate that much of the sand and fine gravel component that accumulated in this transitional sequence was derived from various environments at bathyal, shelf and intertidal depths (0-500 m). The coarser clasts can be confidently identified as being derived locally from eroding Waiheke Group greywacke and Waikato Coal Measures.

Thus, during accumulation of the transitional Waitemata sequence, there was still a landmass or island in the vicinity, with an eroding rocky shoreline interspersed with sandy beaches and a sheltered, mangrove-lined bay or inlet. Offshore there were areas at mid and outer shelf depths accumulating thin sedimentary sequences and supporting rich benthic

communities. The seafloor probably dropped fairly steeply down to bathyal depths and large amounts of the locally-derived shallow water sediment and fauna were transported downslope by subaqueous mass flows.

Further subsidence drowned these nearby land areas before accumulation of the overlying Waitemata Group flysch. Paleocurrent and heavy mineral evidence indicate that the flysch has been transported into the depths of the Waitemata Basin as turbidity currents sourced from the Kaipara area, 50 km to the north-west (Hayward and Smale 1992).

Acknowledgements. We wish to thank Nick de Carteret and Chris Hollis for assistance in the field. We are also grateful to John Buckeridge (Carrington Polytechnic), Jack Grant-Mackie (University of Auckland) and Fred Brook (Department of Conservation, Whangarei) for assistance with identification of some of the fossil barnacles, molluscs and corals, respectively. Graeme Gibson (University of Auckland) kindly gave us access to the Hays Stream microfaunal sample R12/f7627, which he and his 1970 micropaleontology class collected and processed. Some of the fossil illustrations in Figs. 2-6 are adapted from drawings by Ron Brazier (Beu et al. 1990) and the late Jack Marwick (Fleming 1966). We appreciate the helpful comments of Anthony Wright, Brett Stephenson, Chris Hollis (all Auckland Institute and Museum), Jack Grant-Mackie and Fred Brook, who kindly read the draft manuscript.

REFERENCES

BEU, A.G., P.A. MAXWELL and R.C. BRAZIER
1990 Cenozoic Mollusca of New Zealand. *New Zealand Geological Survey Paleontological Bulletin* 58.

BUCKERIDGE, J.S.
1983 Fossil barnacles (Cirripedia: Thoracica) of New Zealand and Australia. *New Zealand Geological Survey Paleontological Bulletin* 50.

CLARK, E. de C.
1905 The fossils of the Waitemata and Papakura Series. *Transactions of the New Zealand Institute* 37: 413-421.

DAWSON, E.W.
1990 The Cenozoic Brachiopoda of New Zealand: A commentary, reference list, and bibliography. *New Zealand Oceanographic Institute Miscellaneous Publication* 103.

FELL, H.B.
1954 Tertiary and Recent Echinoidea of New Zealand. *New Zealand Geological Survey Paleontological Bulletin* 23.

FINLAY, H.J.
1924 Three fossil annelids new to New Zealand. *Transactions of the New Zealand Institute* 55: 448-449.

FLEMING, C.A.
1966 Marwick's illustrations of New Zealand shells, with a checklist of New Zealand Cenozoic Mollusca. *Department of Scientific and Industrial Research Bulletin* 173.

GRENFELL, H.R.
1984 Early Miocene teleost otoliths from Parengarenga Harbour, New Zealand. *New Zealand Journal of Geology and Geophysics* 27: 51-96.

HAYWARD, B.W.
1977 Lower Miocene corals from the Waitakere Ranges, North Auckland, New Zealand. *Journal of the Royal Society of New Zealand* 7: 99-111.
1986 A guide to paleoenvironmental assessment using New Zealand Cenozoic foraminiferal faunas. *New Zealand Geological Survey Report Pal* 109.
1990 Use of foraminiferal data in analysis of Taranaki Basin, New Zealand. *Journal of Foraminiferal Research* 20: 71-83.

HAYWARD, B.W. and F.J. BROOK
1984 Lithostratigraphy of the basal Waitemata Group, Kawau Subgroup (new), Auckland, New Zealand. *New Zealand Journal of Geology and Geophysics* 27: 101-123.

HAYWARD, B.W. and M.A. BUZAS
1979 Taxonomy and paleoecology of early Miocene benthic foraminifera of northern New Zealand and the north Tasman Sea. *Smithsonian Contribution to Paleobiology* 36.

HAYWARD, B.W. and D. SMALE
1992 Heavy minerals and the provenance history of Waitemata Basin sediments (early Miocene, Northland, New Zealand). *New Zealand Journal of Geology and Geophysics* 35: 223-242.

HEALY, J.
1935 Geology of the Hunua-Ramarama area. Unpublished M.Sc. thesis, Geology Department, University of Auckland.

HORNIBROOK, N.deB.
1971 New Zealand Tertiary climate. *Report New Zealand Geological Survey* 47.

HORNIBROOK, N.deB., C.P. STRONG and R.C. BRAZIER
1989 Manual of New Zealand Permian to Pleistocene foraminiferal biostratigraphy. *New Zealand Geological Survey Paleontological Bulletin* 56.

KEAR, D.
1959 Drury coalfield, Auckland. *New Zealand Journal of Geology and Geophysics* 2: 846-869.

LAWS, C.R.
1931 Geology of the Papakura-Hunua district, Franklin County, Auckland. *Transactions of the New Zealand Institute* 62: 37-66.

RICKETTS, B.W., P.F. BALLANCE, B.W. HAYWARD and W. MAYER
1989 Basal Waitemata Group lithofacies: rapid subsidence in an early Miocene interarc basin, New Zealand. *Sedimentology* 36: 559-580.

SCHOFIELD, J.C.
1976 Sheet N48 Mangatawhiri (1st ed.), Geological Map of New Zealand 1:63 360. *DSIR, Wellington.*

SCHWARZHANS, W.
1984 Fish otoliths from the New Zealand Tertiary. *New Zealand Geological Survey Report* 113.

SQUIRES, D.F.
1958 The Cretaceous and Tertiary corals of New Zealand. *New Zealand Geological Survey Paleontological Bulletin* 29.
1962 Additional Cretaceous and Tertiary corals from New Zealand. *Transactions of the Royal Society of New Zealand* 1: 133-150.

STINTON, F.C.
1957 Teleostean otoliths from the Tertiary of New Zealand. *Transactions of the Royal Society of New Zealand* 84: 513-517.

WATERHOUSE, B.C.
1974 Type and standard localities: Papakura Limestone. *New Zealand Journal of Geology and Geophysics* 17: 487-490.

M. EAGLE and B.W. HAYWARD, Auckland Institute and Museum, Private Bag 92018, Auckland.

APPENDIX 1. Systematic list of macrofauna tabulated from Hays Stream (H) and Tipakuri Stream (T) localities. Taxonomy follows Beu et al. (1990) for Mollusca; Stinton (1957), Grenfell (1984) and Schwarzhans (1984) for otoliths; Dawson (1990) for brachiopods; Buckeridge (1983) for barnacles; Squires (1958, 1962) for coelenterates.

	MOLLUSCA	
	BIVALVIA	
NUCULIDAE	*Nucula otamatea* Laws, 1939	H
NUCULANIDAE	*Pseudoportlandica* cf. *solenelloides* (Marshall, 1919)	H
	Ledella pakurangiensis Laws, 1941	H
MALLETIIDAE	*Neilo* n.sp.	H
LIMOPSIDAE	*Limopsis catenata* Suter, 1917	H
	Limopsis zealandica Hutton, 1873	H
	Limopsis sp.	H,T
GLYCYMERIDIDAE	*Glycymerita (Manaia)* cf. *manaiaensis* (Marwick, 1923)	H
	Tucetona aucklandica (Powell, 1938)	H,T
PTERIIDAE	*Pteria oneroaensis* (Powell & Bartrum, 1929)	H
ISOGNOMONIDAE	*Isognomon* aff. *zealandicus* (Hutton in Suter, 1917)	H
PECTINIDAE	*Chlamys fischeri* (Zittel, 1864)	H
	Lentipecten hochstetteri (Zittel, 1864)	H
	Mesopeplum costatostriatum (Marshall, 1918)	H
	Mesopeplum n.sp.	H
	Mesopeplum sp.	H
LIMADAE	*Lima colorata* Hutton, 1873	H,T
OSTREIDAE	*Ostrea* sp.	H
CHAMIDAE	*Chama* n.sp.	H
CARDITIDAE	*"Cyclocardia" awamoensis* (Harris, 1897)	H
	Glyptoactis (Fasciculicardia) subintermedia (Suter, 1917)	H
CRASSATELLIDAE	*Eucrassatella ampla* (Zittel, 1864)	H,T
	Spissatella tralli (Hutton, 1873)	T
MACTRIDAE	*Lutraria trapezoidalis* Powell & Bartrum, 1929	H
MESODESMATIDAE	*Paphies* n.sp.	H
TELLINIDAE	*"Tellina" hesterna* (Powell & Bartrum, 1929)	H
	"Tellina" robini (Finlay, 1924)	H
	Bartrumia oneroaensis (Powell & Bartrum, 1929)	H,T
VENERIDAE	*Kuia vellicata* (Hutton, 1873)	H
	Austrovenus n.sp.	H
	Dosinia (Raina) bensoni Marwick, 1927	H
	Dosinia lambata (Gould, 1850)	T
CORBULIDAE	*Caryocorbula nitens* (Marshall, 1919)	H
	Notocorbula humerosa (Hutton, 1885)	H
	Notocorbula cf. *pumila* (Hutton, 1885)	H
HIATELLIDAE	*Panopea worthingtoni* Hutton, 1873	H
PHOLADIDAE	*Parapholas aucklandica* Powell, 1938	H

	GASTROPODA	
TROCHIDAE	*Zethalia* n.sp.	H
TURBINIDAE	*Sarmaturbo superbus* (Zittel, 1864)	H
CERITHIIDAE	*Zefallacia benesulcata* Powell & Bartrum, 1929	H
	n.gen. & n.sp.	H
PAREORIDAE	*Pareora striolata* (Hutton, 1885)	H
POTAMIDIDAE	*Pyrazus consobrinus* Powell & Bartrum, 1929	H
TURRITELLIDAE	*Maoricolpus waitemataensis* (Powell & Bartrum, 1929)	H
	Tropicolpus (Amplicolpus) gittosinus (Powell & Bartrum, 1929)	H
	Zeacolpus pukeuriensis Marwick, 1934	H
	Zeacolpus tetleyi (Powell & Bartrum, 1929)	H
STRUTHIOLARIIDAE	*Struthiolaria lawsi* Powell & Bartrum, 1929	H,T
CALYPTRAEIDAE	*Crepidula (Maoricrypta)* aff. *opuraensis* Powell & Bartrum, 1929	H
TRIVIIDAE	*Proerato* n.sp.	H
NATICIDAE	*Polinices huttoni* Ihering, 1907	H
	Polinices oneroaensis Powell & Bartrum, 1929	H
	Polinices sp.	H,T
RANELLIDAE	*Cabestana tetleyi* Powell & Bartrum, 1929	H
BUCCINIDAE	*Austrofusus (Neocola) alpha* (Finlay, 1926)	H
	Austrofusus (Neocola) oneroaensis Powell & Bartrum, 1929	H
	Paracominia finlayi (Powell & Bartrum, 1929)	H
	Paracominia lignaria (Powell & Bartrum, 1929)	H
NASSARIIDAE	*Nassarius (Hima) separabilis* (Laws, 1939)	H
MURICIDAE	*Chicoreus (Siratus) komiticus* (Suter, 1917)	H
	Lepsiella intermedia Powell & Bartrum, 1929	H
	Lepsiella maxima Powell & Bartrum, 1929	H
	Lepsiella n.sp.	H
	Pagodula waitemataensis (Powell & Bartrum, 1929)	H
	Pterynotus cf. *kaiparaensis* Fleming, 1962	H
MITRIDAE	*Eumitra nitens* (Marshall, 1918)	H
	Eumitra waitemataensis (Powell & Bartrum, 1929)	H
VOLUTOMITRIDAE	*Proximitra partinoda* Finlay, 1930	H
OLIVIDAE	*Amalda (Baryspira) platycephalia* (Powell & Bartrum, 1929)	H
	Amalda (Baryspira) robusta (Marwick, 1924)	H
	Amalda (Spinaspira) stortha (Olson, 1956)	H
VOLUTIDAE	*Alcithoe (Alcithoe) turrita* (Suter, 1917)	H
	Teremelon tumidor (Finlay, 1926)	H
CONIDAE	*Conilithes wollastoni* Maxwell, 1978	H
	Conus (sensu lato) *thorae* Finlay, 1926	H
	Conus (sensu lato) *armoricus* (Suter, 1917)	H
TEREBRIDAE	*Zeacuminia* cf. *orycta* (Suter, 1917)	H
TURRIDAE	*Anacithara clifdenica* Powell, 1942	H
	Austrotoma excavata (Suter, 1917)	H
	Austrotoma minor (Finlay, 1924)	H
	Bathytoma (Bathytoma) bartrumi Laws, 1939	H
	Gemmula kaiparaensis (Marshall, 1918)	H
	Maudrillia supralaevis Powell, 1942	H
	Tomopleura (Maoritomella) sola (Powell, 1942)	H

ACTEONIDAE	*Acteon oneroaensis* Powell & Bartrum, 1929	H
CYLICHNIDAE	*Cylichnania bartrumi* Marwick, 1931	H
	Cylichnina ennucleata Powell & Bartrum, 1929	H
PYRAMIDELLIDAE	*Chemnitzia brevisutura* Laws, 1937	H
	SCAPHOPODA	
DENTALIIDAE	*Antalis pareorensis* (Pilsbry & Sharp, 1897)	H
	Dentalium mantelli Zittel, 1864	H,T
	Fissidentalium n.sp.	H
LAEVIDENTALIIDAE	*Laevidentalium waihoraense* Emerson, 1954	H
	BRYOZOA	
	gen. & spp. indet.	H
	BRACHIOPODA	
CANCELLOTHYRIDIDAE		
	Terebratulina suessi (Hutton, 1873)	H
	gen. & sp. indet.	H
DALLINIDAE	*Magasella neozelandica* (von Ihering, 1903)	H
HEMITHYRIDIDAE	*Notosaria antipoda* (Thomson, 1918)	H
	POLYCHAETA	
	Sclerostyla ouyenensis (Chapman, 1913)	H
	Spirorbis sp.	H
	gen. & sp. indet.	H
	ECHINOIDEA	
CIDARIDAE	*Phyllacanthus titan* Fell, 1954	H
	CIRRIPEDIA	
ARCHAEOBALANIDAE	*Notobalanus vestitus* (Darwin, 1854)	H
	Tasmanobalanus grantmackiei Buckeridge, 1983	H
SCALPELLIDAE	*Graviscalpellum ungulatum* (Withers, 1913)	H
	?Smilium subplanum (Withers, 1924)	H
	COELENTERATA	
CARYOPHYLLIIDAE	*Caryophyllia japonica* Marenzeller, 1888	H
	Cyathoceras sp.	H
	Notocyathus conicus (Alcock, 1902)	H
	Notocyathus (Paradeltocyathus) pedicellatus Tenison-Woods, 1880	H
	Sphenotrochus sp.	H
	Trochocyathus (Aplocyathus) papakurensis (Clarke, 1905)	H
	n.gen. & n.sp.	H
DENDROPHYLLIIDAE	*Balanophyllia alta* Tenison-Woods, 1880	H
	Dendrophyllia boschmai van der Horst, 1926	H
FAVIIDAE	*Cyphastrea* cf. *chalcidum* (Forskaal, 1775)	H
	Leptastrea cf. *transversa* Klunzinger, 1879	H

FLABELLIDAE	*Flabellum lamellulosum* Alcock, 1902	H
	Flabellum pavoninum Lesson, 1831	H
	Tortoflabellum marwicki Squires, 1962	H
	Truncatoflabellum sphenodeum (Tenison-Woods, 1880)	H
	Truncatoflabellum sp.	H
MELITODIDAE	*Parisis hamiltoni* (Thompson, 1908)	H
OCULINIDAE	*Oculina virgosa* Squires, 1958	H
	Oculina cf. *virgosa* Squires, 1958	H
	CHONDRICHTHYES	
ODONTASPIDIDAE	*Odontaspis elegans* Agassiz, 1843	H
	TELEOSTS	
	gen. & spp. indet. (teeth)	H
APOGONIDAE	*Epigonus* sp.	H
BERYCIDAE	*Centroberyx* cf. *Trachichthodes pulcher* Schwarzhans, 1980	H
BOTHIDAE	*Arnoglossus novus* Schwarzhans, 1980	H
CARAPIDAE	*Carapus* sp.	H
CEPOLIDAE	*Cepola* cf. *macrophthalma* Linnaeus, 1758	H
HOPLICHTHYIDAE	*Hoplichthys multistriatus* Grenfell, 1984	H
MACROURIDAE	*Coelorhynchus australis* (Richardson, 1839)	H
	Coelorhynchus cf. C. *toulai* (Schubert, 1905)	H
MELANONIDAE	*Melanonidarum* aff. *Karrerichthys admirabilis* Schwarzhans, 1980	H

APPENDIX 2. List of foraminifera obtained from Hays and Tipakuri Stream samples. Numbers are abundances (%) in each sample from picks of 100 benthic foraminifera. * = present but not recorded in quantitative pick. Taxonomy follows Hayward and Buzas (1979) and Hornibrook et al. (1989).

1	R12/f8	Hays Stream	inner shelf
2	R12/f9	Hays Stream	mixed inner shelf-upper bathyal
3	R12/f7627	Hays Stream	mixed outer shelf-upper bathyal
4	R12/f14A	Hays Stream	mixed inner-outer shelf
5	S12/f16	Tipakuri Stream	mid-outer shelf
6	S12/f18	Tipakuri Stream	mid-outer shelf

	1	2	3	4	5	6
Alabamina tenuimarginata		*		1		
Amphistegina aucklandica		4		58		
Anomalinoides fasciatus	1		2		2	4
Anomalinoides macraglabra	1					2
Arenodosaria antipoda				3		
Astrononion parki	1					2
Bolivina acerosa					1	1
Bolivina arta			3			1
Bolivina cf. *acerosa*					2	1
Bolivina mantaensis			1		11	2
Bolivina plicatella mera					1	
Bolivina reticulata			17	1		
Bolivina semitruncata					4	3
Bolivinopsis cubensis			3			
Buccella lotella						1
Bueningia creeki	1		1			
Cancris lateralis					2	2
Cassidulina laevigata	1				11	10
Cassidulina margareta						6
Catapsydrax dissimilis		*	*			
Cibicides brevoralis				1		
Cibicides lobatulus			1			
Cibicides mediocris	10		20	13	16	6
Cibicides notocenicus	8	*		3		
Cibicides novozelandicus				1		
Cibicides perforatus	1		*	2		
Cibicides refulgens			1			
Cibicides temperatus	4		13	2	3	1

	1	2	3	4	5	6
Cibicides vortex	2	*	5	5	2	7
Cribrorotalia ornatissimum	11	*	*		7	
Discorbis balcombensis	5				1	
Dorothia minima				1		
Dyocibicides sp.					1	
Ehrenbergina marwicki			*			
Elphidium advenum						1
Elphidium gibsoni	8				1	
Elphidium kanoum						1
Elphidium pseudoinflatum						1
Epistominella cassidulinoides					2	1
Epistominella iota					2	2
Eponides repandus	3		1			
Fissurina laevigata					*	
Fissurina marginata					*	
Florilus stachei	1					
Gaudryina convexa	16					
Gavelinella zealandica		*				
Globigerina ciperoensis					*	
Globigerina falconensis						*
Globigerina woodi		*	*			
Globigerina woodi connecta			*	*		
Globocassidulina subglobosa			1	3	1	4
Globoquadrina dehiscens		*	*	*		
Globorotalia nana		*	*			
Globorotalia semivera					*	
Guttulina problema			1		*	
Gyroidina subzelandica		*	1		2	
Gyroidina zelandica			1	1	3	
Hanzawaia bertheloti			*	1	1	
Hanzawaia cf. *complanata*		*				
Hanzawaia laurisae					1	
Hanzawaia stachei					*	1
Haeuslerella hectori			*			
Haynesina depressula	1		1		*	
Kolesnikovella australis			3			
Lenticulina mamilligera				1		
Lenticulina nitida			1	1		
Lepidocyclina orakiensis orakiensis				*		
Melonis simplex	10		1	1	3	1
Nodosaria filiformis			1			
Nonion cassidulinoides					2	

	1	2	3	4	5	6
Nonionella novozealandica	2		2		7	36
Notorotalia powelli	4	*	2		1	
Oridorsalis umbonatus		*				
Osangularia culter			1			
Pileolina patelliformis					1	
Pileolina radiata	1					
Planoglabratella semiopercularis	1					
Planulina crassa			*			
Quinqueloculina seminula	1					
Rectuvigerina rerensis			*			
Semivulvulina capitata			*			
Siphonina australis			*			
Siphouvigerina proboscidea					1	
Stilostomella fijiensis						1
Stilostomella pomuligera		*	1	1	1	
Stilostomella verneuilii			4			
Textularia hayi	2					
Trifarina sp.						2
Trifarina costornata			2			
Trifarina esuriens					1	
Trifarina parva			3		2	
Uvigerina picki			5	1		
Vaginulinopsis recta			*			
Virgulopsis pustulata					4	
Percentage planktic foraminifera	10	95	75	40	45	25